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Do player performance, real sport experience, and gender affect movement patterns during equivalent exergame?

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Abstract

This study compared the movement patterns of forty-six college students, playing bouts of swimming exergame, while categorized based on their playing performance, gender, and prior experience of real swimming and exergames. Swimming events were divided into normal (controlled by visual feedback) and fast (no feedback) phases and upper limb kinematics were monitored during front crawl event. Those who performed better, completed the game with fewer upper limb cycles and in a shorter time ($p < 0.003$). Prior exergame experience resulted in higher start velocity ($p = 0.019$) and those who were familiarized with this swimming exergame, completed the front crawl event with fewer cycles ($p = 0.022$). Gender and real swimming experience did not affect biomechanical variables. With various playing styles and differences to real swimming movements, the data suggest that the motion capture device is not able to detect complex movements of swimming and previous knowledge of real swimming do not necessarily transfer into better exergame performance. These changes might have happened due to higher adaptation to the exergame. Understanding these patterns may help in the development of more realistic sport exergames and meaningful gameplay.

Keywords: Research methods & experimental design; Biomechanics; Virtual sport; Performance; Front crawl

Introduction

Despite documented benefits of physical activity, many people are still living inactive lifestyles. Interventions for decreasing sedentariness for overweight youth typically fail, because of low motivation and high attrition rates (Sardinha et al., 2012; Summerbell et al., 2005). Youth may also stop regular physical activity during their adolescence, which may lead to weight gain (Slater & Tiggemann, 2010). Moreover, there are some other well-identified contributors to physical inactivity, namely the lack of access to physical education at school (Brownson et al., 2000), being a racial/ethnic minority group (Brodersen, Steptoe, Boniface, & Wardle, 2007), having low socioeconomic status (Kristjansdottir & Vilhjalmsson, 2001), and engaging in prolonged television watching (Hu, Li, Colditz, Willett, & Manson, 2003). As part of screen-based activities, video game playing is increasing among youth, and has changed significantly from arcade games to accessible video games (Lenhart et al., 2008). However, high exposure to video games has raised psychological and physiological concerns (Roberts, Foehr, Rideout, & Brodie, 2003), leading to the design of exergames in which players have to interact using their body (requiring some degree of physical activity). Using Kinect, a low-cost motion capture sensor, players do not have to hold any extra gadgets during the gameplay and the sensor can detect full body joint segments (Zhang, 2012), providing indoor experiencing of many sport-related activities.

According to specificity of training principle, repeating similar movements may provide skilled behavior (Barnett, Ross, Schmidt, & Todd, 1973) and, as sport exergames consist of many repetitive movements, they might potentially be helpful or detrimental in improving fundamental movement skills (FMS) which are the basis of more complex and specific sport motor skills (Lubans, Morgan, Cliff, Barnett, & Okely, 2010). It has been also proposed that for an optimal performance between specific activity (real sport) and a repeated task (sport exergame), task constraints should be similar (Newell, 1989). For example, Downs, (2008), found that putting a golf ball in a Nintendo Wii game, actually led to net gains in the refinement and production of real putting behavior. Such naturally mapped exergame controllers provide an interactive, dynamic, and enjoyable experience and might increase feelings of self-efficacy and learning exercise behavior (McGloin, Farrar, & Krcmar, 2011; Skalski, Tamborini, Shelton, Buncher, & Lindmark, 2011). On the other hand, excessive exergame playing may also lead to injuries, indeed, conditions such as Wii-shoulder (Cowley & Minnaar, 2008), Wiiitis (Bonis, 2007; Nett, Collins, & Sperling, 2008), and X-boxitis have been previously recognized by medical doctors. Specific in-juries and risks associated with excessive practice are important, especially when players are not completely aware of their bodies and surroundings. Therefore, evaluation of movement patterns is essential for designing exergames and realistic sport games should require movements determining good performance.

Previous research suggests that although exergames require active participation, they are usually less demanding than real-world exercises (Graves, Ridgers, & Stratton, 2008). Movements during exergaming are highly different (Levac et al., 2010) and depending on games, consoles, and strategies that different players employ, patterns vary from full body to small wrist movements. For example, it was shown that kinematics of real and virtual tennis differ (Bufton, Campbell, Howie, & Straker, 2014), and experienced real-football players had smaller reaction time and made fewer corrective movements compared to novice players during a virtual football video game (Savelsbergh, Williams, Van Der Kamp, & Ward, 2002). Previous research also showed that quantity of movements in experienced exergame players is not different than the

ones of novice players (Levac et al., 2010). Moreover, physio-logical evaluations show that males and females are equally active during exergaming sessions (Sun, 2013), but there are contradictory results regarding time spent playing exergames between the two genders (Sit, Lam, McKenzie, Sit, & Lam, 2010). While there are non-modifiable challenges during playing sport exergames (e.g. lack of forces from water in swimming exergame or holding a physical racket during tennis), for a more meaningful experience, movement patterns should be as close as possible to real sports. More detailed evaluations are needed to provide evidence for the bene-fits of sport exergames and, if showing movement behavior similar to real sports, they can potentially be a low-cost tool in increasing physical activity and skill acquisition. As research investigating the amount of movement and different strategies of playing in exergames is scarce, we have purposed to compare upper limb kinematics in a swimming exergame between players with different game performance, prior real swimming and exergame experience, and gender.
Methods

Participants

35 male and 11 female college students (mean ± SD 24.4 ± 4.4 vs. 27.3 ± 7.2 years of age, 1.77 ± 0.07 vs. 1.66 ± 0.06 m of height, and 72.7 ± 10.8 vs. 58.4 ± 7.1 kg of body mass, respectively) were recruited through word of mouth, flyers, and online advertisement. The procedures were approved by local ethics committee (Process number: CEFADE 01/2013) and, prior to testing, participants signed the informed consent. Data from participants' preferred upper limbs were considered in the analysis.

Procedures

Twenty-two spherical reflective markers of 20 mm were placed on the anatomical landmarks over the skin (cf. Rab, Petuskey, & Bagley, 2002): 7th cervical vertebrae, acromio-clavicular joints, lateral and medial epicondyles approximating elbow joints, wrist bar thumb side and pinkie side (radial styloid and ulnar styloid), dorsum of the hand just below the head of the second and fifth metacarpal, inferior lower border of scapula bones, sacrum, sternum, anterior-superior, and posterior-superior aspects of iliac crest. The 3D position of each marker was simultaneously recorded at 200 Hz using a 12-camera motion capture system (Qualisys AB, Gothenburg, Sweden) using a specific acquisition software (Qualisys Track Manager, Qualisys AB, Gothenburg, Sweden).

Subjects played different techniques (100 m each) in a swimming exergame designed for Microsoft Xbox and Kinect (Michael Phelps: Push the Limit, 505 Games, Milan, Italy). The gameplay was divided into two phases (normal and fast) and the upper limb kinematics during front crawl was monitored. Players' performances were ranked from 1st to 8th and categorized as "Good" (1st to 4th) and "Bad" (5th to 8th) in a swimming exergame competition. Players ranked their real swimming and exergame experience from 1 to 5 where 1 was novice and 5 was experienced (including front crawl). If subjects played backstroke, breaststroke, or butterfly techniques before front crawl, we considered them as experienced with the exergame (swimming exergame experience).

During the front crawl event, subjects had to stand in front of the Kinect sensor and bend forward (preparatory position; Fig. 1, panel A) and, as soon as they saw the visual command, they had to return back to standing position with upper limbs in front (Fig. 1, panel B). Afterward, subjects had to swing their upper limbs (Fig. 1, panels C, D, and E) to move the avatar in the game. At the middle of the second lap, there was a possibility to swim as fast as possible called “Push the Limit”. At the end of the event, they had to drop their upper limbs (Fig. 1, panel F) and then raise one to finish the race (Fig. 1, panel G). To prevent from too fast or too slow gameplay, an on-screen visual feedback bar indicated if the speed was at the moderate level.

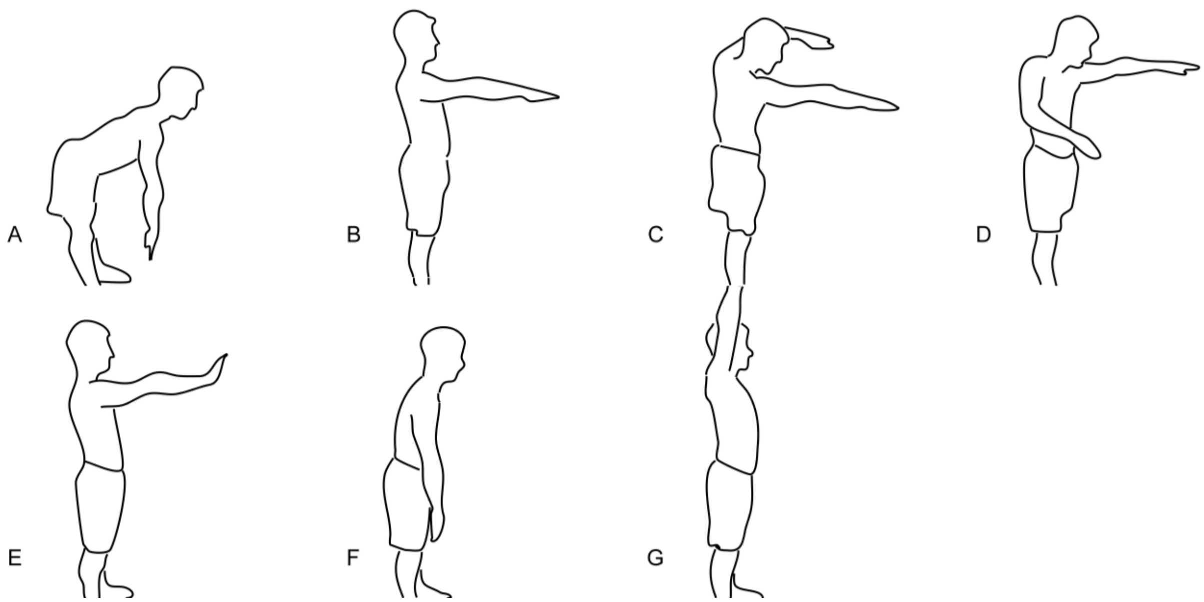

Figure 1. Position of the body in different phases of the front crawl event during playing the exergame (A: getting ready to dive; B: start, C and D: swimming; E: starting a new lap; F and G: terminating the race).

Data collection and analysis

Before each experiment, cameras were calibrated to the measurement volume of 5 m deep by 3 m wide by 3 m high, in front of the Kinect sensor. A 10 s static trial was recorded for each subject while standing in an anatomic position, as the baseline measurements for processing the kinematic data. Subjects were asked to wear bright clothes that neither absorb nor reflect the light that causes gaps in 3D detection/reconstruction (Dutta, 2012). Three consecutive front crawl upper limbs cycles in each phase were considered in the analysis and a 3D motion analysis package (Vis-ual3D, C-Motion, Rockville, MD) was used to compute joint kinematics. The laboratory and segment local coordinate systems were defined as illustrated in Fig. 2, with the local coordinate system defined at the proximal joint center for each segment. For the elbow and hand, the joint centers were located mid-way between the humeral medial and lateral epicondyles and the midway be-tween the markers placed on the second and fifth metacarpals, respectively.

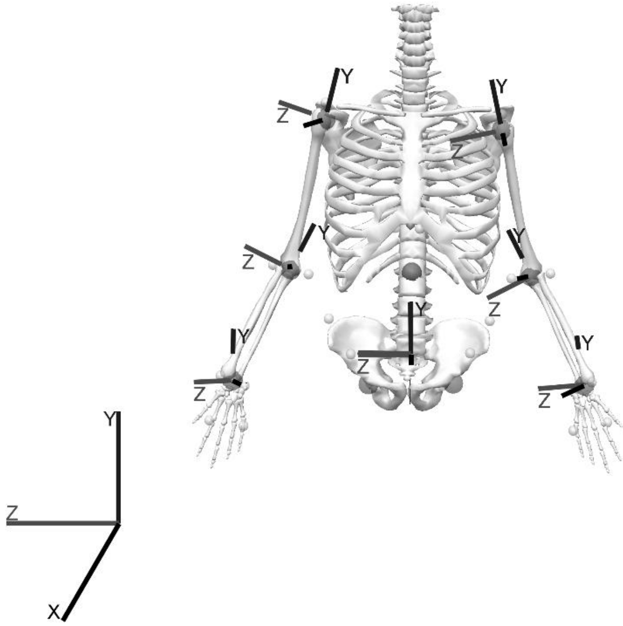

Figure 2. Laboratory and segment coordinate systems of upper body used for processing the kinematic data.

Table 1 lists kinematic variables that were measured during the exergame play and demographic and kinematical data were presented as mean ± SD and subjects within each performing groups were compared using one-way analysis of variance (ANOVA). Normality and homogeneity of variance were checked and, in the case of abnormal distribution and non-homogeneity, alternative statistics were applied. Outcomes of kinematic variables across performing groups (as between-group variables) were also analyzed using multivariate analysis of variance (MANOVA). The level of significance was set to a ¼ 0.05 and IBM SPSS Statistics 20.0 (Chicago, IL) was used for all statistical analyzes. As a priory and to detect differences between groups, power calculation indicated that at least 32 participants should be included (Faul, Erdfelder, Lang, & Buchner, 2007). Sample size calculation was based on a pilot study testing 10 subjects and determinants for calculation were $\alpha = 0.05$ one-tail, power = 0.70, allocation ratio of 0.7, and effect size of 0.8.

Table 1. Different biomechanical parameters and their description used during swimming exergame.

Variables	Title (unit)	Description
1	Total time of event (s)	Measured from the dive in phase until subjects finished the event (Figure 1, panels B and G).
2	Numbers of cycles - normal (n)	Each cycle is defined from the moment when the hand's center is at its maximum X coordinate (Figure 1, panel C) until it returns to the same position.
3	Numbers of cycles - fast (n)	
4	Start velocity ($m.s^{-1}$)	Measured by the velocity of the hand from the starting position to the position where the hand's center is at its maximum X coordinate (Figure 1, panels A and B).
5	Mean velocity - normal ($m.s^{-1}$)	Measured on the hand's center during normal and fast phases.
6	Mean velocity - fast ($m.s^{-1}$)	
7	Max velocity - fast ($m.s^{-1}$)	Is defined as maximum velocity during the fast swimming phase.
8	Hand path distance (m)	Measured by the angular distance covered by the hand.
9	Max arm depth - normal (cm)	Was the distance of hand's to the ground (Figure 1, panels F and G, respectively).
10	Max arm depth - fast (cm)	
11	Max arm height - normal (cm)	Was the distance of hand's to the ground (Figure 1, panels F and G, respectively).
12	Max arm height - fast (cm)	
13	Max arm width - normal (cm)	Measured by the maximum lateral distance of hand's center relative to the shoulder's joint center.
14	Max cycle width - fast (cm)	
15	Elbow angle - normal (°)	Was the angle between the shoulder-to-elbow and the elbow-to-wrist position vectors in both normal and fast phases.
16	Elbow angle - fast (°)	
17	Trunk rotation - normal (°)	Was the angle change created by vector connecting the two shoulders' joint centers and vector connecting the superior markers of iliac crest in the static trial, projected onto the X,Z plane.
18	Trunk rotation - fast (°)	

Results

Table 2 presents the mean ± SD for kinematic variables within performing groups. Participants with good performance completed the event faster ($H(1) = 17.53$, $p = 0.001$) and with fewer cycles both in normal ($H(1) = 8.87$, $p = 0.003$) and fast ($H(1) = 11.45$, $p = 0.001$) swimming phases. Subjects with prior exergame experience presented higher start velocity ($F(1,44) = 5.98$, $p = 0.019$) and lowered their hands more during the fast swimming phase (minimum cycle depth – fast; $H(1) = 5.02$, $p = 0.025$). Participants with previous swimming exergame experience had fewer cycles (total numbers of cycles – normal; $H(1) = 5.25$, $p = 0.022$) and lowered their hands less during normal phase of swimming (minimum cycle depth – normal; $H(1) = 4.29$, $p = 0.038$). Prior real swimming experience and gender did not cause differences in kinematical variables ($p > 0.05$). Considering participants' gaming performances, prior real swimming experience, prior exergame experience, gender, and prior swimming exergame experience, all together, there were also no differences in kinematic variables based on ($p > 0.05$).

Figure 3 provides a typical example of movement patterns during front crawl for a player with bad performance and the other with good performance. Despite differences from real sport, it is evident that bad performers were usually playing closer to real swimming, while good performers' movements were enough to win the game.

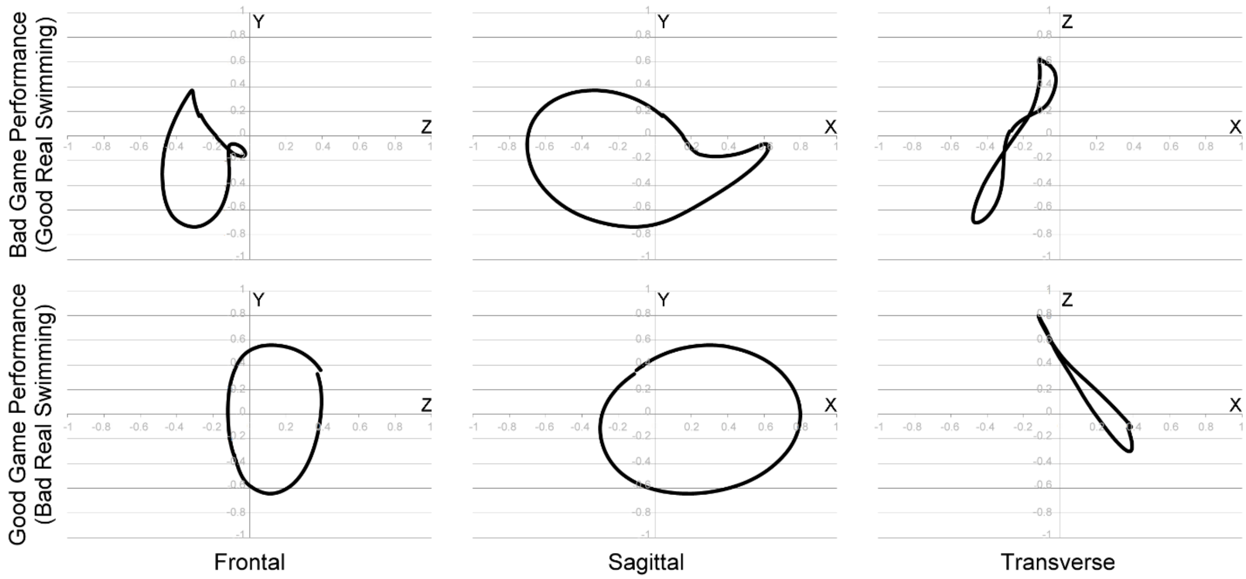

Figure 3. Sample path of movement of preferred hand in one complete cycle of front crawl during exergame playing between a good and bad performance.

Table 2. Mean ± SD values of exergame front crawl kinematic variables.

Variables	Exergame Performance		Real Swimming Experience		Exergame Experience		Gender		Swimming exergame experience	
	Good (n=33)	Bad (n=13)	Swimr (n=35)	Non-Swimr (n=11)	Exp (n=17)	Novice (n=29)	Male (n=35)	Female (n=11)	Exp (n=26)	Novice (n=20)
1	48.45±1.58 [18.38]*	53.31±4.11 [36.50]	49.97±3.58 [24.24]	49.36±2.50 [21.14]	49.24±1.82 [22.79]	50.17±3.96 [23.91]	49.29±2.69 [22.01]	51.55±4.61 [28.23]	48.81±1.49 [20.56]	51.15±4 .49 [27.33]
2	27.67±2.60 [19.83]*	32.77±6.00 [32.81]	29.20±4.73 [23.21]	28.82±3.57 [24.41]	27.82±1.70 [22.15]	29.86±5.35 [24.29]	28.11±2.82 [21.73]	32.27±6.90 [29.14]	27.46±1.72 [19.56]	31.25±5.88 [28.63]*
3	9.39±1.47 [19.38]*	12.46±3.23 [33.96]	10.23±2.23 [24.21]	10.36±3.35 [21.23]	9.71±1.82 [21.24]	10.59±2.81 [24.83]	9.94±2.04 [22.67]	11.27±3.55 [26.14]	9.50±1.53 [20.42]	11.25±3.16 [27.50]
4	5.35±1.28	4.71±1.51	5.21±1.32	5.02±1.55	5.78±1.25*	4.81±1.32	5.25±1.27	4.90±1.66	5.39±1.17	4.88±1.57
5	2.64±0.66	2.51±0.70	2.65±0.73	2.47±0.42	2.54±0.58	2.64±0.72	2.62±0.71	2.56±0.51	2.60±0.57	2.61±0.79
6	4.17±1.04	3.70±0.92	4.01±1.12	4.10±0.69	3.94±1.19	4.08±0.93	4.08±1.12	3.89±0.64	4.26±1.07	3.75±0.91
7	6.41±1.42	6.12±1.72	6.45±1.62	5.97±0.95	6.18±1.47	6.42±1.53	6.43±1.63	6.01±0.93	6.55±1.54	6.04±1.41
8	117.85±23.67	127.15±37.04	120.51±30	120.36±19.70	117.82±25.99	122.03±29.41	117.91±28.30	128.64±26.49	120.81±24.57	120.05±32.53
9	80.48±12.99 [21.77]	89.03±19.11 [27.88]	82.93±16.16 [23.21]	82.78±12.60 [24.41]	88.75±18.68 [27.94]	79.46±11.90 [20.90]	84.19±16.35 [24.34]	78.77±10.63 [20.82]	79.56±15.61 [19.90]	87.23±13.97 [28.18]*
10	78.50±13.56 [21.73]	86.30±16.50 [28.00]	81.96±15.29 [24.64]	76.74±12.39 [19.86]	87.70±17.74 [29.29]*	76.61±10.96 [20.10]	82.47±16.29 [25.01]	75.10±4.89 [18.68]	78.58±16.00 [20.87]	83.48±12.66 [26.93]
11	172.79±23.02	170.01±16.43	172.40±22.06	170.74±19.20	176.64±24.18	169.29±19.21	174.29±21.90	164.73±17.85	172.48±25.31	171.39±14.93
12	177.05±23.94	170.82±18.56	176.25±23.67	172.23±19.10	180.41±25.79	172.29±20.25	177.26±23.48	169.01±18.77	178.17±25.87	171.55±17.18
13	37.86±10.86	34.65±12.87	36.73±11.78	37.65±10.64	36.40±13.24	37.27±10.44	37.59±12.06	34.92±9.25	37.14±11.27	36.71±11.88
14	40.20±8.54	36.83±12.63	39.20±10.07	39.97±9.50	38.84±10.12	39.48±9.84	38.48±10.74	41.69±5.88	40.01±9.41	38.24±10.53
15	112.97±16.07 [23.85]	110.15±12.57 [22.62]	113.09±14.99 [24.53]	109.27±15.72 [20.23]	113.12±17.89 [23.65]	111.62±13.48 [23.41]	113.34±16.19 [24.33]	108.45±10.61 [20.86]	113.73±16.45 [24.88]	110.15±13.23 [21.70]
16	112.70±15.72	109.38±10.47	111.40±14.28	112.91±15.43	110.76±17.57	112.34±12.49	111.74±15..85	111.82±8.85	112.42±15.93	110.90±12.49
17	39.76±13.63 [24.94]	34.38±17.36 [9.85]	40.17±15.85 [25.39]	32.09±8.58 [17.50]	41.29±15.15 [26.50]	36.45±14.52 [21.74]	39.60±15.47 [24.40]	33.91±11.91 [20.64]	39.35±13.66 [25.19]	36.80±16.37 [21.30]
18	33.61±12.91 [21.89]	38.69±13.23 [27.58]	36.66±13.25 [25.11]	29.91±11.51 [18.36]	36.00±14.90 [24.32]	34.48±12.10 [23.02]	35.46±13.78 [23.56]	33.73±10.93 [23.32]	34.00±11.93 [23.08]	36.40±14.61 [24.05]

Data are presented as mean ± SD or [mean rank]; Swimr = Swimmer; Exp = Experienced; n = Number; M = Male; F = Female; Elbow angles were calculated throughout each cycle; *: differences were observed between the two groups within each performing categories.

Discussion

The main purpose of this study was to characterize and compare kinematic variables in a swimming exergame between players with different real-swimming experience, exergame experience, gender, and performance status. Results showed that the performing groups were similar in the majority of kinematic variables.

Performance

There was a difference in total number of cycles between bad and good performers, as the former (69% real swimmers) were trying to apply the same real-swimming patterns during their game play while the latter movements were sufficiently enough to win the race. In many cases, bad performers had to repeat the movements while good performers could simply rotate their upper limbs and proceed within the game. During the fast swimming phase, good performers maintained a constant rhythm to complete the event, reserved more energy (by following constant speed), and did not have to exert as much as bad performers. Bad performers had to compensate by swinging their upper limbs faster resulting in increased time of play and increased number of cycles. As mentioned before, exergames could benefit skill development, if players with movements similar to real sport are rewarded with higher scores (Papastergiou, 2009). Contrary to Reynolds et al. (2014), in our study the sensor failed to detect precise movements of swimming (Galna et al., 2014), seeming that simple pattern recognition and timings are more crucial than the accuracy of movements based on the real swimming techniques. The simplistic graphics (i.e. the feedback bar) may have encouraged players to focus on core elements of game play and not on their movements (Gerling et al., 2011). Therefore, this exergame might not be applicable in teaching and practicing swimming outside the swimming pool.

Swimming experience

There were no differences in biomechanical parameters between swimmers and non-swimmers. Players with real-swimming experience had the intention to swim correctly and had to adapt their movements with the visual feedback bar, probably due to the delays in providing sensory feedbacks. As they also lost many points (energy reserves) during their adaptations, they had to compensate in the fast swimming phase by swinging their arms faster. Stroke rate, fatigue, and higher velocity decreases propelling efficiency (e_p) or the ratio of useful to total amount of work in real swimming (Toussaint et al., 2006). Real swimmers were considering this parameter during their game play, trying to swim properly to maximize their performance. That is why real swimmers had greater hand path distance (similar to stroke length). Since the sensor failed to detect their correct swimming movements and as they figured out the mechanisms of the game play, they changed their technique after some time. This is another reason to doubt the usefulness of the game to help real swimming performance skill development. Lack of differences might be due to applying different strategies by different players and effects of learning, which led the players to switch from swimming technically (correctly) to pragmatically (winning the game).

Exergame experience

Prior exergame experience did not influence most of the kinematic parameters except the start velocity which is contrary to previous research indicating that exergame experience causes greater movement quantity (Levac et al., 2010). Participants without prior experience were flexing their body more (Figure 1 A), and were lifting more body weight returning to the dive in position (Figure 1 B), resulting in lower start velocity. Lack of differences in other variables (e.g. hand path distance) might be due to learning different strategies even after a short exposure to the exergame. These results are opposite to previous findings showing that prior experience with exergames provides greater quantity and quality of movements (Levac et al., 2010).

Gender

According to hand path distance, participants played the game with the same intensity, which is contrary to the reports that male subjects play exergames more actively (Lam et al., 2011; Siegel et al., 2009) and that boys play video games for longer periods than girls (Graves et al., 2008). Weight of the upper limbs might be one of the reasons why females were more active and having greater hand path distance covered during playing. On the other hand, male players played the game faster (based on maximum velocity), in accordance with the literature (Sharp et al., 1982). Moreover, contrary to real swimming (Seifert et al., 2007), our males and females were not different in both start and average velocities and hand path distance, which was expected due to different swimming conditions and applied forces on the body.

Swimming exergame experience

Previous swimming exergame resulted in lower time of swimming, which might be justified with the fact that although players played different techniques, requiring different movement patterns, they learned the mechanisms underlying the game. Players who had their first exposure to the game during front crawl did not explore obvious differences in task restrictions between exergame and real swimming (Davids, Button, & Bennett, 2008). That is why they used fewer arm cycles and were trying to adapt their movements with the feedback bar, resulting in decreased arms' swings. While there are several ways to show gameplay mechanics (e.g. trial-and-error, instruction manuals, or verbal instructions), they might add extra time to the first gaming session, having a nontrivial effect on overall game experience (Tobin & Grondin, 2009). While previous research showed that a pregame tutorial training does not affect pose accuracy as means of game performance (Whittinghill et al., 2014) our results show that those who played this game before (which also included a pregame tutorial) completed the game in shorter time.

Comparison to real swimming

Because of different body positions and lack of forces applied to the body (swimming in the air which is 800 times lower than water in density), differences in kinematics between the virtual game and real activity were not surprising. While we observed higher values of swimming segment velocity (normal phase: 3 ± 1 m.s^{-1} and fast phase: 4 ± 1 m.s^{-1}), previous research reported average velocity in a group of sprinters and distance swimmers to be 1.81 ± 0.1 m.s^{-1} and 1.80 ± 0.1 m.s^{-1}, respectively (McCabe et al., 2011). De Jesus et al. (2012) also reported the velocity in a group of water polo players to be 1.50 ± 0.1 $m.s^{-1}$. However, it should be noted that duration and difference of these investigations were different compared to our study. During different phases of the game, we observed elbow flexion values ranging from 109 ± 16 to 113 ± 16 degrees and trunk rotation ranging from 34 ± 17 to 40 ± 16 degrees, while elbow flexion and trunk rotation of 156 ± 15 and 62 ± 4 degrees, respectively were previously reported for front crawl (Payton et al., 1999). During 200 m front crawl at race pace, elbow flexion ranged from 40 ± 12 to 152 ± 6 degrees (Figueiredo et al., 2013). Such differences might have happened as players were constantly looking at the screen to receive feedback and therefore, avoided rotating their trunk. It was also stated before that skilled swimmers maintained a more constant stroke length than less skilled (Chollet et al., 1997) and therefore, based on our findings, we can understand that in this exergame, good performance does not necessarily mean following correct real movements (Figure 3).

The optimal goal of sport exergames is to mimic the real sport movements, but due to passive-playing nature of the games, players often follow different ways to exert (e.g. head movements increase virtually induced illusory self-motion or Vection resulting to exerting more; Ash et al., 2011). In our study, participants frequently reported that their real movements of swimming were not completely applied in the game, which encouraged them to do simple movements just to win the game. Such comparisons might reveal differences in anticipatory performance in which skilled players are more attentive to the mechanics of the game and such information could be interpreted as learning or adaptation to the movements. Another explanation might be the feedback given to the player during exergaming which is dynamically linked to user input and as players change their game play, the feedback remains unchanged. This might encourage players to maintain their newly adopted game play and exert less.

Movement patterns during exergame play are highly varied and gaming platforms might impose some of these limitations on the players (Pasch et al., 2009). Sport exergame designers could use the biomechanical characterization data during their game development to provide a more meaningful experience, especially if participation in real sport happens before exergame playing (Mueller et al., 2009). There are a number of modifiable and non-modifiable parameters associated with sports exergames. Non-modifiable constraints (lack of actual forces from water or holding a physical racket in hand or positioning) may result in considerable differences in movement patterns. Modifiable considerations, such as input control device and audiovisual feedbacks, currently differ between different consoles and might allow cheating during game play and affect posture and muscle loading (Lui, Szeto, & Jones, 2011). For example, using Nintendo Wii, players can simply move their wrist instead of complete movement in tennis exergame. Proper design is particularly important as many games consist of repetitive movements and, based on the game conditions (e.g. playing against an opponent), movements could be more intense. As enjoyment and other factors may contribute to high exposure to these games, our results could help game designers to prevent musculoskeletal symptoms and could be helpful in designing harder game levels.

The strengths of the current study include using accurate 3D motion capture system and analyzing software, comparing several kinematic variables in variety of performing groups, and addressing limitations of previous studies. A limitation of the study was that most of our volunteers had sport science background and were physically active. Although we did not explain the mechanisms underlying the game, participants' behaviors might have been influenced by the novelty of the game, meaning that some players might have continued swimming correctly even when they found out that their movements were not translated into the game. While we calculated our sample size based on exergame performance, power in other performing groups might have been compromised and, therefore, considering more subjects to increase the power in different performing groups is advisable.Conclusions

In this study, we provided kinematic characterization of swimming exergame and compared the parameters in different performing groups. Although most of the variables were not different among performing groups, different subjects had different game play strategies. As there are differences in upper limb kinematics between the game and real swimming, our data suggests that better real swimming performance does not necessarily transform into better game performance. As the motion capture sensor does not detect the correct movements of real swimming, it does not encourage players to swim properly and therefore, it might not be a proper tool for practicing real swimming. Detailed biomechanical characterization of exergames might address these issues and provide a safer and more meaningful game play. A future follow-up evaluation is also necessary to identify potential movement changes in subjects' behaviors throughout the game.

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